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Biotechnology, Prospects for Development in Emerging Economies

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Abstract

Throughout history, innovation has driven progress and helped people address the problem of the age. This progress has not been achieved without pain and controversy, at times war and famine and pestilence thwart our best endeavors.

Despite setbacks, people throughout the world continue to strive to understand the natural world, to pursue truth and beauty, and to create a better world for themselves and their children.

Science has a role to play in all these pursuits. However, the very power of the new discoveries in the biological sciences raises fears that these discoveries will not be used wisely. Many believe that they will:

- *Accelerate the destruction of the natural environment,*
- *Damage human health*
- *Concentrate too much power in the hands of a few global companies*
- *Widen the gap between the rich and the poor, within and between nations.*

The task of the scholars of today is to analyze where Plant Biotechnology can lead to technical innovation and how these can be used wisely:

- *To improve agriculture productivity,*
- *To conserve nature resources,*
- *To create wealth especially for poor people in developing countries.*

Powerful tools provided by Biotechnology in recent years have had a profound impact on the food and agriculture sector worldwide. Innovation, production and processing methods have revolutionized many traditional systems, and the world's capacity to generate food products for its growing population has evolved at an unprecedented rate.

These developments have naturally been accompanied by radical changes in economic forces and social organization as well as in management of the earth's productive resources. Our very relationship with nature has been overturned by technological advances that enable us not only to determine genetic improvement through selective breeding but also to modify living organisms and create novel genetic combinations in the quest for stronger and more productive plants animals and fish.

Understanding such developments invariably give rise to controversy, and arguments for and against their implementation tend to be intense and emotionally-charged.

THE CHALLENGE

The annual world agriculture growth rate has decreased from 3% in the 1960s to 2% in the last decade.

- By 2020, worldwide per capita availability of food is projected to increase around 7%,
- For developing countries by 9% (Pinstrup-Andersen, and Rosegrant 1999).

The paradox is that despite the increasing availability of food, of the 840 million people or 13% of the global population, who are food insecure.

- 4.5 billion inhabitants are from the developing countries
- 48% from Asia
- 35% from Africa
- 17% from Latin America.

Of these 840 million, at least 200 million are malnourished children.

It is also paradoxical that food insecurity is so prevalent at a time when global food prices are generally in decline, and when

- World cereal production has doubled since 1960
- 1990 per capital food production increased 37%
- Calories supplied increased 35%
- Real food prices fell by almost 50% (Mc Calla 1998).

The basic cause of the paradox is the intrinsic link between poverty and food security. Simply put, people's access to food depends on income.

Ensuring their access to sufficient nutritious food at affordable prices is also an important component of global food security strategies.

Biotechnological research needs to respond to these challenges, to improve the livelihood of the rural poor and ensure the increased availability of nutritious food at affordable prices for the urban poor.

THE STATUS OF BIOTECHNOLOGY

Biotechnology is any technological application that uses biological systems, living organisms or part thereof to make or modify a product or process for a specific use. This even covers traditional techniques of making wine and cheese.

Modem biotechnology generally means modification of living organisms (plants, animal and fish) through the manipulation of genes.

There are two main types of biotechnological processes.

1. The first uses genetic information to speed up and improve conventional plant or animal breeding.
2. The second (and more advanced) modifies the genetic pattern of a plant or animal to create a new organism.

Traditionally, a plant breeder tries to exchange genes between two plants to produce offspring that have desired traits. This is done by transferring the male pollen of one plant to the female organ of another.

This cross breeding, however, is limited to exchanges between the same, or very closely-related species. It can also take a long time to achieve desired results and frequently, characteristics of interest do not exist in any related species.

Biotechnology enables plant breeders to bring together in one plant useful genes from a wide range of living sources, not just from within the crop species or from closely related plants.

This powerful tool allows plant breeders to do faster what they have been doing for years – generate superior plant varieties and expand the possibilities beyond the limits imposed by conventional plant breeding.

In the developed world, there is clear evidence that the use of Genetically Modify crops has resulted in significant benefits. These include:

- Higher crop yields
- Reduced farm cost
- Increased farm profit
- Improvement in the environment
- Flexibility in crop management.

There has been substantial developments in biotechnology and genetic engineering in the last 20 years, which offer new prospects for increased agricultural production. However, while biotechnology has the potential to produce crops and livestock that are more efficient, more productive, easier to produce, and use less agrichemicals, consumer acceptance of genetically modified foods will continue to be a challenge for global application of the results of biotechnological research.

According to recent statistics, in 2000 the global area under genetically modified crops was 45 million hectares and this is expected to be 85 million hectares in 2003 (6% of the total arable land.) The recent release of genetically modified rice called golden rice, that is rich in vitamin A and could cure Vitamin A deficiency of 124 million children worldwide, underscores the potential of biotechnology for the future.

The most common Genetic Modify (GM) crops are soybean (58% of GM crop total), maize (23%), cotton (12 percent) and canola (7%), with smaller amounts of potato, squash and papaya.

In 2000, Argentina, Canada, China and the United States accounted for 99 percent of the global GM crop area. Other countries growing commercial GM crops were Australia, Bulgaria, France, Germany, Mexico, Portugal, Romania, South Africa, Spain, Ukraine and Uruguay.

Many developing countries are involved in GMO research. Field-testing of GMO's is underway in:

- Africa: Egypt, Kenya, South Africa and Zimbabwe are testing one or more of the following: GM wheat, groundnut, cotton, squash, sugar cane and sweet potato.
- Asia: China, India, Indonesia, Malaysia, Pakistan, Philippines and Thailand are testing one or more of the following: GM tobacco, aubergine, tomato, cotton, sorghum and bananas.
- Latin America: Argentina, Bolivia, Brazil, Cuba and Mexico are testing 60 GMOs belonging to more than 20 species, including papaya, tobacco, cotton, maize, potato, coffee, sugar cane, sunflower and sugar beet.

POTENTIAL BENEFITS TO THE REGION

Current biotechnology can increase crop yields and reduce production costs, even for small-scale farmers in developing countries, who make up a large part of the world's poor and hungry population. Even more important for such farmers, many of whom struggle to make a living on marginal land, is ongoing research into drought resistant and salt-tolerant crops. Biotechnology can help even the landless poor by enriching staple foods, such as through the addition of essential vitamins. These potential benefits can include:

Agronomic Applications

Tissue culture / Micro propagation techniques:

- Production of healthier plants, allowing for savings in the costs of plant protection treatments
- Uniformity of phenotypic characteristics in clones produced
- Uniformity in production
- Easily reproducible experimental system (hence expected results)
- Availability of planting material year-round
- Selection for superior quality
- Selection for higher production
- Labour is reduced to a minimum between subculture (no weeding, irrigation, spraying, etc whilst in the lab)
- Reduced time from planting to harvest

Increased nutritional value of staple foods: Genes are being inserted into rice to make it produce beta-carotene, which the body converts into vitamin A. This experimental transgenic "golden rice" has the potential to reduce vitamin A deficiency, a leading cause of blindness and a significant factor in many child deaths.

Reduced environmental impact: Scientists are developing trees with modified cell lignin content. When used to make pulp and paper, the modified wood requires less processing with harsh chemicals.

Increased fish yield: Researchers have modified the gene that governs growth hormones in tilapia, a farmed fish, offering the prospect of increased yield and greater availability of fish protein in local diets.

Increased nutrient absorption by livestock: Animal feed under development will improve animals' absorption of phosphorus. This reduces the phosphorus in animal waste, which pollutes groundwater.

Tolerance of poor environmental conditions: Scientists are working to produce transgenic crops that are drought-resistant or salt-tolerant allowing the crops to be grown on marginal land.

Herbal medicine: Taxol is a cancer treatment derived from the bark of a fir tree. The manufacture of enough Taxol to give an average cancer patient one cycle of treatment requires the bark of between seven and ten 100 = year old trees. These trees are expensive but money is not the real problem.

This species of fir has been designated as endangered, and it is illegal to log it for commercial proposes. However, not all is lost: tissue culture techniques have enabled the active component to be grow in a laboratory, thus guaranteeing doctors and cancer patients a steady supply of the drug at a reasonable price.

Microorganisms for cleaning the environment: Scientists have already created bioagents effective in treating waste. Now they are working on the following ways to prevent waste from being produced.

- Bioagents effective in treating waste.
- Biodegradable plastic is seen as one of green industry's most promising products.
- Biological effect of decomposition.

APPLICATION WITH THE GREATEST POTENTIAL

Biotech Soybean

Soybean is the oil crop of greatest economic relevance in the world. Its beans contain proportionally more essential amino acids than meat, thus making it one of the most important food crops today.

Herbicide-tolerant soybean: Herbicide-tolerant soybean varieties contain a gene that provides resistance to one of two broad-spectrums, environmentally- benign herbicides.

This modified soybean provides better weed control and reduces crop injury. It also improves farm efficiency by optimizing yield, using arable land more efficiently, saving time for the farmer, and increasing the flexibility of crop rotation. It also encourages the adoption of no-till farming-an important part of soil conservation practice.

Oleic acid soybean: This modified soybean contains high levels of oleic acid, a monounsaturated fat. According to health nutritionists, monounsaturated fats are considered "good" fats compared with saturated fats found in beef, pork, hard cheeses, and other dairy products.

Biotech Corn

Corn is one of the three most important grains of the world.

Herbicide-tolerant corn: These corn varieties work in a similar manner to herbicide-tolerant soybean. It allows growers better flexibility in using certain herbicides to control weeds that can damage crops.

Insect-resistant corn: This modified corn contains a built-in insecticidal protein from a naturally occurring soil microorganism *(Bt)* that gives corn plants season-long protection from corn borers. The Bt protein has been used safely as an organic insect control agent for over 40 years. This means most farmers do not have to spray insecticide to protect corn from those insects, which cause significant damage and yield loss in many areas. Bt corn also reduces toxin contamination arising from fungal attack on the damaged grain. (Argentina, Australia, Canada, Denmark, EU, Japan, Netherlands, South Africa, Switzerland, UK and the US.)

High laurate canola: These canola varieties contain high levels of laurate. Oil processed from these novel varieties is similar to coconut and palm oils.

This new canola oil is being sold to the food industry for use in chocolate candy coatings, coffee whiteners, icings, frostings, and whipped toppings. Even the cosmetic industry uses it. (Canada and the US.)

Biotech Cotton

Insect-resistant: This modified cotton works similarly to insect-resistant corn. It contains a protein that provides the plant with season-long protection from budworms and bollworms. The need for additional insecticide applications for these pests is reduced or eliminated. (Argentina, Australia, Canada, China, Japan, Mexico, South Africa, and the US.)

Insect-resistant potato: This biotech potato works similarly to insect-resistant corn. It contains a protein that provides the plant with a built -in protection from the Colorado potato beetle. Thus, this potato needs no additional protection for this pest, benefiting farmers, consumers, and the environment. (Canada, Japan, and the US.)

Biotech Tomato

Delayed-ripening tomato: The delayed-ripening tomato became the first genetically-modified food crop to be produced in a developed country. These tomato varieties have extended shelf life. They contain a gene that slows the natural softening process that accompanies ripening.

These tomatoes spend more days on the vine than other tomatoes thus resulting in better flavor. Further, the longer shelf life has commercial advantages in harvesting and shipping that can reduce the costs of production. (Canada and the US.)

Biotech Papaya

Virus-resistant papaya: This Hawaiian-developed papaya contains a viral gene that encodes for the coat protein of papaya ringspot virus (PRSV). This protein provides the papaya plant with built-in protection against PRSV. This biotech papaya works similarly to virus resistant potato. (US)

FUTURE DEVELOPMENTS

Developments in Modern Biotechnology

Modem biotechnology is evolving rapidly. It is expected that new methods being developed will help address some of the concerns about the current "generation" of GM products. For example, questions raised with regard to the introduction of genes encoding antibiotic resistance have led to the development of alternative strategies. Many other mechanisms for selecting transformed plants now exist. Where antibiotic resistance markers are used, mechanisms exist to remove them from the transformed food plant.

One of the issues concerning the safety assessment of GM foods is whether gene insertion would affect vital metabolic pathways in the host organisms which could have adverse implications for human health. This situation is no different to the one encountered with classical breeding methods. Learning from the success of yeast artificial chromosomes, the development of plant artificial chromosomes (PAC) promises to be a powerful candidate for the next generation vector in plant transformation. PAC would allow the introduced genetic material to be precisely defined, and to be introduced and stably maintained within the plant without disrupting any existing genetic elements.

Mechanisms for introducing hybrid sterility already exist. These and other transformations that reduce compatibility, or the ability to compete in the wild, will help ensure that any potential problems associated with the transfer of introduced genes to non-transformed crops of the same type will be minimized.

Improvement of agricultural crops through modern biotechnology has primarily focused on the identification and isolation of genes that control important *agronomic* traits of food plants (first generation of GM plants). Food crops have been modified through insertion of new traits or the inhibition of existing gene functions, resulting in plants with improved herbicide tolerance or pest resistance. Evidence from field trials indicates that, in addition to introducing further improvements in agronomic properties, future genetic modification of plants will be focused on the improvement of food quality characteristics and on industrial and medicinal applications. In the future, it is likely that products will be developed that are not substantially equivalent to conventional counterparts.

Agronomic Applications

All of the crops that have currently been genetically modified to increase their resistance to attack by specific insects, notably the European corn borer, produce a single crystalline protein derived from the bacterium B. thuringiensis. To increase efficacy, broaden activity and delay the development of insect resistance, strategies have been developed to introduce a number of different genes into crops. This may be done through conventional crosses between two GM plants, or through using a GM plant as the parent line for further transformation events, and is sometimes referred to as pyramiding genes or gene stacking. Genes coding for proteinase inhibitors, ct-amylase inhibitors, lectins, chitinases or cytolytic endotoxins have all been successfully examined for their ability to increase the insect resistance of a wide variety of crop plants. To date, these resistance factors have been used individually; in the future, they may be used in various combinations (including with the Bacillus protein) to produce transgenic plants with resistance to a far greater range of insect pests than at present.

Improving the capacity of crop plants to cope with specific environmental stress conditions is an important goal, given the need to bring marginal land into production. For instance, plants have been developed with the increased availability of phosphorus in animal feeds, through insertion of genes coding for phytase (alfalfa), or for phosphate transport proteins *(Arabidopsis,* tomato, potato). Aluminum tolerance has been increased in tobacco, papaya, rice and corn through insertion of genes coding for citrate synthases. Further research is focused on isolating, characterizing and expressing multiple genes that help crops cope with drought, salt, or heat/cold stress conditions.

Food Quality and Public Health

Detoxification of mycotoxins (fumonisin) by maize plants has been demonstrated through inserting genes from micro-organisms able to metabolise mycotoxins, while insertion of cowpea trypsin inhibitor in tobacco showed efficacy against mycotoxin-producing strains of *Aspergillus* and *Fusarium.* Identification of genes responsible for producing vitamins, carotenoids and many other bioactive compounds has provided the means to modify the content of these compounds in plants. Soybean and lupin have been modified to express higher concentrations of essential amino acids, potato and sugar beet to express a higher content of starch and novel carbohydrates, soybean and sunflower to express a higher oleic acid content; tomato has been modified with enhanced levels of beta-carotene and lycopene, and rice with higher Vitamin A precursors and iron content.

In the future, it may be possible to remove or reduce the allergenic potential of foods to which sections of the population develop an allergic response. Some of these applications could be useful in combating diseases like childhood blindness and anemia, as well as those resulting from protein deficiencies in developing countries. The development of foods with health protection or health promotion claims attracts considerable attention, but many issues such as identification of biosynthetic pathways and their regulation, characterization of nutritional and toxic ranges of the modified food, still need to be elucidated.

Medicinal Applications

Modified plants incorporating antigenic proteins of human pathogens may soon be used as oral vaccines. Raw potatoes, containing antigens of hepatitis B virus or cholera toxin, are being tested in humans for oral immunization. Altered forms of monoclonal antibodies against oral and gut pathogens can be produced by plants: for example, the expression of the Norwalk virus capsid protein, resulting in protection against viral gastroenteritis. Certain fruits, like banana, may serve as attractive carriers for edible vaccines. Production of therapeutic proteins in plants is promising, but clinical efficacy, differences in glycosylation patterns, allergenicity and stability need to be carefully studied. If such modified plants are intended for medical purposes, they must be assessed in the same manner as other medicinal products.

Industrial applications: Growing plants for other purposes than to provide food is not new. Crop plants may be grown to produce, for example, textiles or fuel. Through genetic modification, some new or expanding uses of crop plants for industrial purposes are possible. Crops grown for high production of seeds, like canola, corn, cereals and rice, are suitable for chemical production since much of the product can be formed in the plant seed and is then readily harvested and stable during storage.

Use of products from GM plants for industrial applications can provide more cost-effective routes to high-value pharmaceuticals or a source of sustainable feedstock for the chemical industry. The oleic acid content of soybean has been increased, rendering this crop suitable for production of fatty acid polymers (estolides), components of hydraulic fluids. Oleic acid may also be converted into epoxy or acetylenic derivatives, components of paints and coatings. Canola, genetically modified to produce a detergent (high lauric acid) for industrial use, has completed field trials, and other varieties have been modified in order to produce biodegradable plastics based on polyhydroxybutyrate. GM maize is already used for commercial production of beta-glucuronidase (GUS) and chicken egg white, avidin. Aprotinin for the pharmaceuticals industry made from GM maize is on the market.

A POLICY TO PROMOTE FURTHER USE OF BIOTECHNOLOGY

Safety testing strategies for the "new generation" of GM products need to be designed according to the nature of the crop's modification or its intended use, especially if this is for medicinal purposes. In such cases, applying the principle of substantial equivalence is likely to lead to the conclusion that the new product cannot be considered comparable to its counterpart since profound alterations in the food crop's composition may have taken place.

In the case of genes coding for proteins to enhance the plant's ability to resist pests, information may need to be generated on the specific biological action of the protein. For example, it may be necessary to understand how the protein binds to receptors in the insect and how it mediates its toxic effect. Animal testing may be necessary to look for toxicity in mammals. For non-proteinaceous "pesticides," depending on their characteristics, it may be necessary to test for the potential of the substance to cause immunotoxic or endocrine effects, or the ability to disrupt digestive function. Generating such information may involve either whole food or single test substance testing. Because it is possible that introduced substances may interact with one another in gene stacking situations, it may be necessary to test for potentiation or antagonism.

A similar approach should be taken to assess the safety and functionality of foods that have been altered in their content of components with added nutritional value. Specific nutritional and toxicological studies must be designed in order to determine the safety and beneficial dose ranges of the new food ingredient or food. However, the scientific basis for demonstrating the safety and functionality of bioactive compounds is still fragile, and more research is needed to underpin health and other claims for food components. Many traits that may be of interest from the nutritional point of view are controlled by multiple genes involved in regulating biochemical pathways that are imperfectly understood. New molecular techniques such as micro-array DNA/RNA technology will be of great value in elucidating complex genetic control mechanisms in food plants, and in studies of interactions between bioactive food components and humans or animals.

The development of non-food crops presents a number of risk management challenges, associated in particular with cross-pollination. It will be important to consider food safety implications as part of the approval process for such crops. The use of by-products from such crops as animal feed is an additional issue that would need to be addressed before such crops could be approved for commercial cultivation.

To identify unintended effects due to genetic modification, a systematic analytical comparison is made between the agronomic properties and composition of the GM organism and those of its parent or other direct comparator, grown under conditions that are as identical as possible. Compositional analysis is normally on single components like macro- and micronutrients and plant-specific anti-nutrients or toxicants. Animal experimentation with complex foods to assess unintended effects can have severe drawbacks. It may not be possible to devise suitable diets containing substantial amounts of the test material without incurring nutritional imbalances, low sensitivity and small safety margins.

The process of assessing novel (including GM) foods needs to be sufficiently comprehensive to be able to address concerns regarding the safety of such foods now and in the future. New technological advances therefore need to be incorporated into the assessment procedure as soon as they are considered reliable enough to yield meaningful results. Various novel techniques were considered at the OECD workshop held in Aussois in 1997.

Detection of unintended effects at a higher integration level than single compound/component analysis can be carried out through (a) DNA sequence and gene expression analysis (genoniics), (b) protein expression analysis (proteomics) and (c) secondary metabolite profiling (metabolomics). A combination of these techniques could provide detailed information on the nature and extent of potential changes in the metabolism of GM food plants, which may or may not be of toxicological concern. Results from these analyses would guide further toxicological studies, if necessary.

The Aussois workshop considered whether techniques such as micro-arrays and proteoniics were robust enough to use in the routine safety assessment of novel (including GM) foods. Although it was felt that such techniques could potentially be very useful in helping to characterize even more precisely than at present any differences between GM and non-GM crops, they were still in their infancy. Much more development work would be needed before they could be utilized in the regulatory framework. The workshop concluded that current assessments of GM foods are thorough, and that they utilize reliable techniques to keep risk to a minimum, but that techniques which built on and refined the current substantial equivalent assessment would be welcome once validated. It was felt that these techniques show sufficient promise to be worth investigating further in the context of crops.

Conclusion

1. The need to produce sufficient food for the world's population is urgent, compelling, and complementary to improving human health..
2. Requirements for international standards, regulation and legislation need to be put in place to deal with the issue of the release and determination of the risk of GMOs.
3. Developing countries need to develop knowledge capabilities, the human resources and the appropriate infra-structure to address the issue of the release of GMOs as it relates to human

and animal health, the environment, international trade and treaties on international trade.

RECOMMENDATION

1. Research needs to respond to these challenges, so as to improve the livelihood of the rural poor and ensure the increased availability of nutritious food at affordable prices for the urban poor.
2. The need for a comprehensive cost/benefit analysis and health impact assessment of GMOs.
3. Determination of the effect of GMOs on farming practices.
4. Segregation of GM foods at source to enable identification and traceability of GM products - this would facilitate monitoring in the interest of public health.
5. Comprehensive assessment to determine if GM crop with pesticide and herbicide resistance result on an increase or decrease in the use of these agri-chemicals.
6. Long- term studies to determine the environment, the food chain, and the fate of metabolic transgenic DNA in humans and animal.
7. Socio-economic, culture impact assessments.
8. Implications for world trade and world agreements.

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